SUPPORTING DECONSTRUCTION PRACTICES WITH INFORMATION SYSTEMS USING ETHNOGRAPHIC-ACTION RESEARCH

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Socio-environmental pressures motivate the construction industry to adopt working practices that enable the reuse of building elements. Deconstruction, as an alternative to demolition, is a major lever for more efficient resource management and enables closed-loop material cycles. Information systems have potential benefits for deconstruction practices, but their implementations are limited by a lack of understanding on how demolition workers create, exchange and communicate information and what artefacts they thereby use. This research has therefore two goals: understanding on-site information requirements in deconstruction projects and exploring how information systems can be iteratively developed and implemented into these project contexts. Through applying an ethnographic-action research methodology on a real-world deconstruction project, two information systems are iteratively developed and implemented: (I) a virtual environment to support tagging façade elements, and (II) a 4D model to support deconstruction planning. Insights are provided - firstly - into deconstruction routines and the tacit knowledge that demolition workers possess and use to deal with these routines, and - secondly - into how the two information systems supported the practitioners in their ongoing project works. These ethnographic-action perspectives provide new ways for researchers and practitioners to support deconstruction practices with information systems.

Keywords: deconstruction, ethnographic-action research, information technology

INTRODUCTION

Resource scarcity, sustainability challenges and stringent policies motivate the construction industry to adopt working practices that facilitate the reuse of building elements. Deconstruction management is a major lever to enable closed-loop material cycles. As an alternative to knocking down buildings with crushing force, Kibert (2016, 480) describes deconstruction as “construction in reverse” in which a building is disassembled for the purpose of reusing its elements. Deconstruction preserves the embodied energy of building elements and can lead to reduced carbon emissions, costs and pollution (Iacovidou and Purnell, 2016). A shift from demolition to deconstruction seems imperative given that end-of-life activities generate one of the largest single waste streams worldwide (Cheshire, 2016). Up to date, however, the end of life for a building typically consists of the complete elimination of all of its parts (Thomsen, Schultmann, and Kohler, 2011).

Adopting a non-conventional deconstruction strategy necessitates a number of changes in the design and planning of these types of projects. Design factors favouring the

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disassemble-ability of a building include the use of prefabricated components, modular components, an open building plan, a layering approach, a standard structural grid and retractable foundations (Akinade *et al*., 2017). Building materials need to be durable and non-toxic with bolt/nuts joints (i.e. mechanical connections) instead of gluing. Planning for deconstruction involves assessing the effects of various parameters like cost, energy use, travel distances and carbon footprint (Akbarnezhad, Ong, and Chandra, 2014). Research into these areas is, however, mostly conceptual and often lacks substantial evidence from practice.

To further disassembly and reuse, a detailed understanding of demolition workers' (best practice) routines in deconstruction is urgently needed. Practitioners rely heavily on practice-based learning (Löwstedt, 2015) and the majority of their constructability knowledge is not explicit but implicit (Phelps and Horman, 2009). Dominant construction methodologies, largely rooted within the positivist tradition, are limited in capturing the tacit knowledge, materials and socialities implicated in the on-site work practices of these workers (Pink, Tutt, Dainty, and Gibb, 2010). Few studies have sought to understand the situated body of construction knowledge that demolition workers possess, and which is mobilized mainly in practices on a site. Little is thus known about how demolition workers create, exchange and communicate information and what artefacts they thereby use.

Understanding the information requirements in deconstruction projects opens up possibilities to implement relevant information systems. For related industries, Olorunniwo and Li (2010) found that information sharing and collaboration practices positively affect a company's ability to handle product returns. Promising benefits in the design, planning and construction of new buildings has also fostered the construction industry's interest in (new) information systems, such as Building Information Models (BIM), which represent physical and functional characteristics of a facility in a virtual model (Eastman, Teicholz, Sacks, and Liston, 2011; Succar, 2009). BIM implementations in demolition/deconstruction projects are nevertheless scarce (Volk, Stengel, and Schultmann, 2014). Research into end-of-life activities focuses mainly on (BIM-based) information systems for existing conditions modelling or pre-demolition audits and frequently lacks empirical reflections (cf. Won and Cheng, 2017). Consequently, little is known about how information systems can be implemented in real-world deconstruction projects.

This study’s research goal is therefore twofold: understanding on-site information requirements in deconstruction projects and exploring how information systems can be iteratively developed and implemented into these project contexts.

RESEARCH METHODOLOGY

This research adopts an ethnographic-action research approach for the development of two information systems. This approach integrates techniques from both ethnographic and action research methodologies (Hartmann, Fischer, and Haymaker, 2009). Ethnography is traditionally deployed by anthropologists to describe a human culture from a native’s point of view (Spradley, 1980). Action research aims at building and testing theory within the context of solving an immediate practical problem in a real setting (Azhar, Ahmad, and Sein, 2009). Developing information systems can benefit from both methodologies: ethnography allows researchers to develop a detailed understanding of the practitioners’ information requirements and through action research they can program and customize new information systems. Hartmann *et al*., (2009) describe the ethnographic-action methodology as an iterative, four-stage research cycle of

(1) ethnographic observations, (2) identification of work routines, (3) information system development and (4) information system implementation on the project.

The research methodology was applied on a real-world project: the deconstruction of a nursing home in the Netherlands. A general contractor, specialized in temporary and semi-permanent buildings, had constructed this two-story building - with a gross floor area of approximately 2400 m2 - in 2012. The firm has systematized its production and, as such, assembles buildings mainly with prefabricated, modular elements. Foundations, floors, roofs, columns and façade elements can be 'mixed and matched' well, which enables the firm to take back its own elements at the end of one life-cycle and use them in another project. To that end, it hired one (fixed) demolition contractor for disassembling the nursing home and organizing the necessary transports. Most of the building's structural elements were planned to be reused for the construction of a school in another part of the country. To support the demolition contractor with on-site deconstruction practices, we developed and implemented two information systems on this case project.

Data was collected and analysed in various ways. The first mentioned author obtained access to the building site after passing for an official health and safety course for construction works (VCA-VOL), which the general contractor and the demolition contractor both demanded from him. While spending approximately 250 h on the site, he closely observed deconstruction practices during the entire project. The researcher also sought to understand the demolition workers' information requirements by doing what they were doing. Consequently, he became an "active participant" (Spradley, 1980, 80) in a wide range of tasks such as installing construction fencing, removing suspended ceiling, moving equipment around, cutting cables, stripping isolation, sorting materials, and rigging/hoisting loads. He kept a field diary to note important observations and took over 800 pictures and movies, which is in line with "recent innovative approaches to doing ethnography" (Pink *et al*., 2010, 649). The researcher also conducted semi-structured interviews with key informants and collected many project documents from both contractors, including the (original) construction drawings and the deconstruction schedule. He recorded (and later transcribed) the practitioners' interactions with, and discussions about, the two information systems that were developed during the course of the project. His analysis of the obtained data focused on integrating an (ethnographic-oriented) understanding of the on-site information requirements in deconstruction projects with an (action-oriented) understanding how information systems can be iteratively developed and implemented into these project contexts.

RESULTS

Deconstruction practices can be dirty, dusty and dangerous. The usage of digital tools and technologies at these sites is very limited. Demolition workers traditionally rely on 2D drawings, forms and other project documents to plan and execute the work. The site which the leading ethnographic-action researcher visited for many weeks was no different. Its site office had a wall on which several such documents were attached: a project schedule, the (original) floor, foundation and roof plans, a report of the Dutch Cable and Pipeline Information Centre and - for emergencies - a document with travel directions to the nearest hospital. The site supervisor was the only one with a laptop. While he saw benefits in providing the foreman with a laptop (or tablet) as well, upper management had repeatedly declined this request for it being "unnecessary". In this non-digital environment, the researcher iteratively developed and implemented two information systems: (I) a virtual environment to support tagging façade elements and (II) a 4D model to support deconstruction planning.

Information System I: A Virtual Environment to Support Tagging Façade Elements

"This type of projects is more strategic," said one of the temporary demolition workers when the ethnographic-action researcher observed how the worker cleaned up the ceiling. The planned reuse of almost the entire façade brought some extra complexities to the deconstruction project. The demolition contractor had, for example, instructed researcher and other new workers on the job to "perform soft-stripping carefully to prevent damage" to the modular façade elements. The demolition contractor also had to tag these elements to enable the general contractor planning and controlling where each element would be assembled in the new building. Interviews with designers and project leaders of the general contractor had revealed a logistical process where a building site is supplied with building elements either directly from a to-be-deconstructed building or indirectly from the general contractor's warehouse with already deconstructed elements. In the focal project, (only) the façade elements had to be tagged on-site according to a disassembly drawing that one of the general contractor's designers had made.

An opportunity was identified to support this tagging project routine with an information system (Table 1). The disassembly drawing displayed four exterior views of the building with hand-written codes above or below each façade element. "However, we are always tagging the elements from the inside of the building," said the foreman when we discussed the routine. The four-digit code on the far left of the drawing must then be written on the element on the far right. "We must [thus] think in mirror image," complemented the site supervisor. This could be confusing, particularly when also other building elements (like columns) need to be coded as well and one would "need to walk around with multiple drawings." During this discussion, the researcher proposed to make the required information three-dimensionally available to them. Though reluctant at first, both men decided to "give it a try."

Table 1: Iterative development and implementation of a virtual environment

Research stage	Iteration 1	Iteration 2	Iteration 3
Ethnographic observation	All façade elements need to be tagged (numbered) on site	Façade elements have different destinations	Rainwater is pouring into building: laptop needs protection
Identification of work routines	2D 'disassembly drawing' is used with exterior views	Colours on (original) 'disassembly drawing' indicate destinations	Procedure requires multiple hands: navigating and tagging
Information system development	2D exterior views and numbers are combined in a 3D (BIM) model with company colours	Colour of 3D numbers (Model Text) is updated in line with drawings	Laptop with virtual environment is put on crates on a warehouse cart
Information system implementation on the project	Demonstration of the virtual environment to foreman	Trial on site with laptop in the hand	Site supervisor uses virtual environment to tag elements on site

The initial result was a virtual environment that integrated the four exterior views into a 3D model. The design of the nursing home had initially (primarily) been represented by 2D drawings. The researcher had, however, also received two BIM models, each containing (only) parts of the foundations, floors, roofs, columns and wind braces. Since one of the models also contained a façade object library (though incomplete), the researcher decided to use that one as a basis to model the (then) existing conditions, i.e. a complete 3D model yet without interior walls. He used a 3D Model Text feature to add the codes from the four exterior disassembly views to the model - using the demolition contractor's house style colour. This model was finally exported and prepared for usage into a 3D model viewer, the 'virtual environment.'

This information system was then iteratively revised in two steps. When the researcher asked the foreman to verify whether he had correctly taken over the numbers from the drawings, the foreman revealed that it would probably be very helpful during the façade tagging routine. He also asked whether it would be possible to use different colours for different codes in the model. The researcher then found out that, next to the numbers, colour coding is important to organize the logistical process: green façade elements were reserved for the construction of the school, blue ones would be stored at a warehouse of the general contractor (until they could be used in another suitable project) and the red ones were classified as waste. He consequently adapted the colour of the 3D codes in the virtual environment. After this, the researcher experienced that it would be impractical to carry around the laptop in the actual building while navigating in the virtual environment at the same time - let alone do the actual tagging. In the hands-on spirit he had observed earlier with the (fellow) demolition workers - "there is a solution for everything" - he found a warehouse cart and a couple of crates that he used to create some sort of walkable desk. The researcher put the laptop (with the virtual environment) on top of this and used a bag to protect it against the rainwater that was then pouring into the building.

This information system replaced the disassembly drawing during the tagging of the façade elements. "Normally," the site supervisor said, "somebody holds the drawing, [another] walks around with a roll of tape and [a third person] writes down the numbers." This time, however, the site supervisor first attached some tape on each of the façade elements himself. Apparently not completely confident about how to use the system, he asked the researcher to navigate around in the virtual environment while he would write the codes on the pieces of tape. Soon after they started tagging, the foreman came by to see how everything worked. "It is great," said the site supervisor and the foreman agreed. While joking about the places that the site supervisor could virtually visit, he tried to navigate in the virtual environment. Even though he accidentally pressed a button that reset the avatar's position, both men concluded it was very easy to use. The site supervisor then continued tagging all façade elements without the researcher's further help in navigating within the virtual environment (Figure 1). Afterwards, he reflected that this system helped him to get "a quick overview" of the building and that it worked "easier than a drawing." The different colours enabled him to see directly where the façade elements would need to be transported to. "I find it all quite nice. I had not expected this." He also requested the researcher to install the software at his own laptop and suggested that the general contractor could just insert the codes into the model and send it to him. "I think that saves some time." The information system could be improved by adding two letters that indicate whether a façade has either a left-swinging or right-swinging window.

Information System II: A 4D Model to Support Deconstruction Planning

One day, two new temporary demolition workers started on the project. The site supervisor welcomed them in the site office and informed them about safety regulations at the workplace.

Figure 1: Overview of new routine - on-site use of a virtual environment for tagging elements

He then pointed to two large floor plans and explained how he kept track of the work's progress: "the pink parts are already finished." The ceiling still had to be cleaned up so that roof elements could be reused: this is what "the new guys" would be doing today. "I will explain to you how," said the site supervisor and he went ahead to the nursing home that was being deconstructed. "You can take this," he referred to rolling scaffolding once inside, "and use it to remove all those things on the ceiling." The introduction ended with instructions about separating different types of waste. When the demolition workers started with the task they were just assigned to, the site supervisor proceeded to check what other people were doing.

Allocating tasks and progress monitoring was later identified as an opportunity to develop an information system (Table 2). The site supervisor was responsible for the overall deconstruction planning. He had pinned a graphical representation of this planning (Gantt chart) to one of the site office's walls - visible for everyone. The planning contained 23 tasks like "removing suspended ceiling", "demolishing internal walls first floor (cleaning up)" and "hoisting façade, timber frame, roofs and columns". The required number of people (1-6 workers) was written behind each of these tasks. Next to the schedule, several 2D drawings and floor plans were hanging on which the site supervisor marked parts that were completed. The information needed for planning the nursing home's deconstruction was thus dispersed over several documents. The site supervisor and/or the foreman (therefore) preferred to allocate deconstruction tasks to the demolition workers "in 3D, outside!"

To provide new opportunities for deconstruction planning, a 4D model was developed by linking schedule information to a 3D (BIM) model. The 3D model that the ethnographic-action researcher created earlier (for the virtual environment) contained foundations, floors, roofs, columns, wind braces, façades and some other elements - all modelled as distinct parametric objects. The researcher decided to connect this model to part of the schedule: hoisting of the façade elements.

Table 2: Iterative development and implementation of a 4D model

Research stage	Iteration 1	Iteration 2	Iteration 3
Ethnographic observation	Site supervisor and foreman allocate demolition tasks on site	Sequence of lifting façade elements is determined by a worker on the roof	Perceived difference between practice and theory regarding planning
Identification of work routines	Gantt chart and 2D drawings attached to the wall represent plan	Two workers on the ground need to detach loads and group façade elements	Planning must be abstract enough to deal with fluctuations in duration
Information system development	Façade elements linked to distinct disassembly activities in a 4D model	Colour of façade elements updated to indicate destinations (90% transparent)	4D model links product groups and activities to align with overall schedule
Information system implementation on the project	Presentation of 4D model (of façade) during lunch break with workers	4D model (of façade) is shown to and discussed with site supervisor	4D model (of entire project) is shown to and discussed with foreman

This was then one of the first upcoming tasks. Several demolition workers, including the foreman and site supervisor, estimated that the duration of that task would be two days. The researcher split the task in many sub-tasks (one for each façade element) to create a more detailed schedule. Based on the foreman's educated guess regarding the likely hoisting sequence, he linked all elements to a sub-task. This resulted in a 4D model that showed the sequenced deconstruction of the façade over time.

Some revisions followed after a demonstration of this 4D model during a lunchbreak with all six demolition workers present that day (including the subcontracted crane operator). Sitting in the site office, the researcher put his laptop in the centre of the table - next to the toaster - explained its purpose and started the simulation. When the last façade element was virtually deconstructed, the workers joked that they already "completed" the project. Then, more serious, they questioned the usefulness of the model. One demolition worker said that "it is not correct any longer if something is delayed" and that the schedule on the wall could "be adapted easier". The crane operator, though interested in how the researcher had made this 4D model, did not find it helpful in determining which element to hoist first as that was determined by "the guy on the roof" (attaching the rigging components to the load). He "is the CEO of the roof. If [he] decides: we go left, then we will go to the left. And if he goes to the right, we will go in that direction," said the foreman. This person missed having an overview of the entire project and could not see where the different elements would need to be transported to. Considering these comments, the researcher first added colours indicating the different destinations for the materials. The site supervisor nevertheless gave similar comments on that version. After that, the researcher added more objects to the 3D model, such as the suspended ceilings and internal walls, and linked the overall schedule to the product groups instead of individual elements. This resulted in a (simplified) 4D model for the complete project (Figure 2).

This information system was further field-tested near the end of the project. In a few working sessions, the researcher demonstrated the 4D model and explained potential benefits, like visualizing the deconstruction sequences, progress monitoring or identifying space-time conflicts. However, the practitioners saw little value in it and no decisions were made based on the model. "For planning purposes, it is perhaps nice to show how long it takes us [to disassemble something] … but we [already] know that," said the site supervisor. There is no need to visualize or simulate the impact of potential delays either. "Sometimes, it can happen that a few façade elements are more difficult to disassemble because the screws … do not want to get out. But the guys then automatically work a bit longer." Regarding allocating tasks to (new) demolition workers, for example those that do not speak the Dutch language, the site supervisor speculated that it may "perhaps be nice for them to watch it." He and another senior demolition worker shared the view that the 4D simulation "is more something for those working at the office [of the general contractor], to see how things are going in practice." When the general contractor's project leader visited the site, he indeed showed great interest in seeing the model. During another meeting, the foreman similarly questioned the value of 4D models for on-site deconstruction planning. However, inspired by the information system, he suggested that they could prepare better for a project if other aspects could be viewed and interacted with, such as the site layout and the position and turning radius of a crane in 3D.

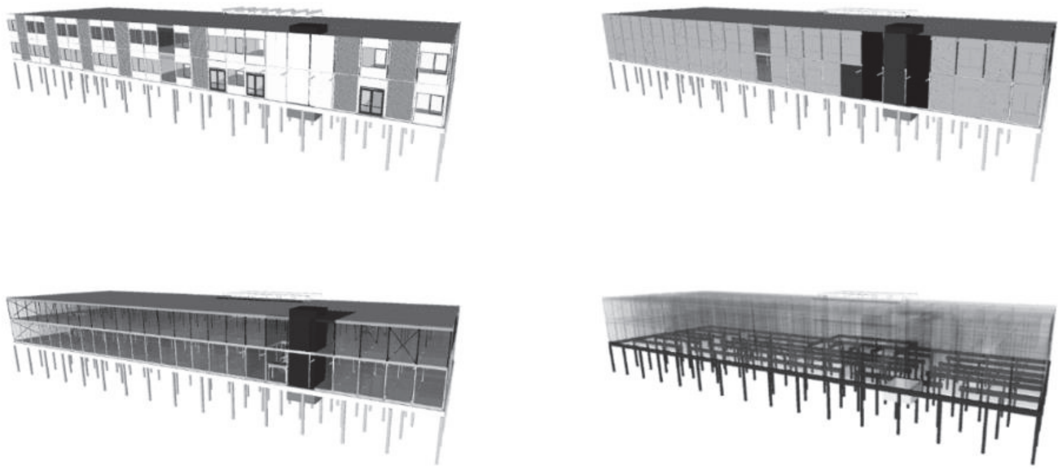

Figure 2: Snapshots of a 4D model that supports deconstruction planning

DISCUSSION

This study's ethnographic-action research approach enabled us to develop and implement two information systems that support on-site deconstruction practices. On one hand, we provided insights about the local routines and the tacit knowledge that demolition workers possess and use to deal with these routines. On the other hand, we offered insights about how the two information systems supported the practitioners in their ongoing project works. The study thereby offers two main contributions.

First, this research demonstrated that virtual environments can support demolition workers in tagging façade elements. Practitioners need information to efficiently plan and control the reuse of building elements after their disassembly. Demolition workers here established a routine to tag façade elements on-site using a 2D drawing provided by the general contractor. The first mentioned researcher integrated the necessary information (four exterior views, numbers and color-coding) within a virtual environment that runs on a laptop. This information system helped the demolition workers through offering them the required information from their own perspective. The benefits included a quick overview of the building in 3D, no indoor mental translation (mirroring) of the exterior views, insight into the future destination of façade elements, easy virtual navigability and a fast procedure on site.

Second, this work showed that 4D models can limitedly support on-site deconstruction planning. An overall project schedule and a set of 2D drawings on which the work's progress is monitored are the main artefacts practitioners used to this end. As the established project routine, deconstruction tasks are mainly allocated on-site by the site supervisor and/or foreman with reference to the (actual) building elements. The researcher created a 4D model by linking the drawings (combined in a 3D model) with the project schedule. This information system visualized and simulated the main deconstruction tasks over time. The 4D model gave the demolition workers an "interesting" overview of the planned deconstruction sequences and could potentially inform new workers. However, little to no evidence was found that the information system could support the demolition workers with analysing the impacts of delays, allocating tasks and progress monitoring.

These ethnographic-action perspectives have several implications for research and practice. This paper provides evidence that the research methodology applied is suitable for developing and implementing information systems during the demolition phase. The study thereby provided a better understanding of the information that is created, exchanged and communicated during deconstruction works and of the artefacts that demolition workers use to do so. That highlighted the importance of (as-built) documentation for deconstruction, from which we suggest that construction drawings and other documents need to be maintained, updated and passed on during the entire life-cycle of a building (i.e. not only from the general contractor to the building owner/facility manager) so that the demolition contractor can - eventually - take advantage from them as well. The work also demonstrated that demolition workers can further reap the benefits of information systems when those are customized to their local working routines. More research, including literal replications (Yin, 2013, 327), is needed to further strengthen this study's findings and to identify new opportunities for information systems to support deconstruction practices (like on-site logistics).

CONCLUSIONS

Information systems can leverage deconstruction practices on a building site. The empirical insights of on-site information usages that this study provides, complement previous conceptual studies that focused mostly on design and building material-related factors in deconstruction. Ethnographic methods here revealed that demolition workers need information (I) to tag reusable building/façade elements and (II) to plan deconstruction tasks. Action-oriented methods subsequently provided insights into (I) how a virtual environment can beneficially present the necessary information from a user's perspective in the first routine and (II) how a 4D model can visualize and simulate deconstruction tasks over time in the second routine. The resulting ethnographic-action perspectives offer a unique understanding of the on-site information requirements in deconstruction projects and explain how information systems can be iteratively developed and implemented into these project contexts.

REFERENCES

Akbarnezhad, A, Ong, K C G and Chandra, L R (2014) Economic and environmental assessment of deconstruction strategies using Building Information Modeling. *Automation in Construction*, 37(**1**), 131-144.

Akinade, O O, Oyedele, L O, Ajayi, S O, Bilal, M, Alaka, H A, Owolabi, H A, Kadiri, K O (2017) Design for Deconstruction (DfD) Critical success factors for diverting end-of-life waste from landfills. *Waste Management*, 60(**1**), 3-13.

Azhar, S, Ahmad, I and Sein, M K (2009) Action research as a proactive research method for construction engineering and management. *Journal of Construction Engineering and Management*, 136(**1**), 87-98.

Cheshire, D (2016) *Building Revolutions: Applying the Circular Economy to the Built Environment*. Newcastle upon Tyne: RIBA Publishing.

Eastman, C, Teicholz, P, Sacks, R and Liston, K (2011) *BIM Handbook: A Guide to Building Information Modelling*. Hoboken, NJ, USA: John Wiley and Sons.

Hartmann, T, Fischer, M and Haymaker, J (2009) Implementing information systems with project teams using ethnographic-action research. *Advanced Engineering Informatics*, 23(**1**), 57-67.

Iacovidou, E and Purnell, P (2016) Mining the physical infrastructure: Opportunities, barriers and interventions in promoting structural components reuse. *Science of the Total Environment*, 557-558, 791-807.

Kibert, C J (2016) *Sustainable Construction: Green Building Design and Delivery*. Hoboken, NJ, USA: John Wiley and Sons.

Löwstedt, M (2015) 'Taking off my glasses in order to see': Exploring practice on a building site using self-reflexive ethnography. *Construction Management and Economics*, 33(**5-6**), 404-414.

Olorunniwo, F O and Li, X (2010) Information sharing and collaboration practices in reverse logistics. *Supply Chain Management: An International Journal*, 15(**6**), 454-462.

Phelps, A F and Horman, M J (2009) Ethnographic theory-building research in construction. *Journal of Construction Engineering and Management*, 136(**1**), 58-65.

Pink, S, Tutt, D, Dainty, A and Gibb, A (2010) ethnographic methodologies for construction research: Knowing, practice and interventions. *Building Research and Information*, 38(**6**), 647-659.

Spradley, J P (1980) *Participant Observation*. New York: Holt, Rinehart and Wineston.

Succar, B (2009) Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction*, 18(**3**), 357-375.

Thomsen, A, Schultmann, F and Kohler, N (2011) Deconstruction, demolition and destruction. *Building Research and Information*, 39(**4**), 327-332. doi:10 1080/09613218 2011 585785.

Volk, R, Stengel, J and Schultmann, F (2014) Building Information Modeling (BIM) for existing buildings: Literature review and future needs. *Automation in Construction*, 38(**1**), 109-127.

Won, J and Cheng, J C P (2017) Identifying potential opportunities of Building Information Modeling for construction and demolition waste management and minimization. *Automation in Construction*, 79(**1**), 3-18.

Yin, R K (2013) Validity and generalization in future case study evaluations. *Evaluation*, 19(**3**), 321-332.